INTEGRATED REFLECTANCE/RAMAN MICROSPECTROMETER

Final Report

JPL Task 979

Pantazis Mouroulis, Space Experiments Systems &Technology Section (387)
Daniel W. Wilson, Paul D. Maker, In-situ Technology & Experiments Systems (384)

A. OBJECTIVES

We sought to prove the feasibility of a miniaturized instrument that would enable correlative reflectance and Raman microspectroscopy, performed on the same sample on the surface of a planetary body, with special reference to Mars. The instrument has two portions, joined by a common optical head which allows extraction of a reflectance or Raman signal from the same position on the sample with only minor repositioning, on the order of 100 μm. The instrument combines the following capabilities: confocal imaging at two different resolution/range levels, reflectance spectroscopy in the 400-2500 nm region with a resolution of 10 nm, and Raman spectroscopy over 4000 cm^{-1} with an average resolution of 3.3 cm^{-1}. The instrument can also serve as an expandable platform for adding fluorescence spectroscopy, or for examining samples from a distance of several meters while using the same spectrometer. In the course of this investigation, an additional capability was added: wide-field color imaging, to solve the problem of providing context for the spectral observations.

B. PROGRESS AND RESULTS

1) Design of front collection optics. This task has been completed successfully. An innovative lens system has been designed that combines not only the optics for the Raman and reflectance spectrometers, as originally envisioned, but also a miniature CCD camera lens, which would be very useful in providing context information. The front optic is shown in Fig. 1. The confocal collection part is a common Schwarzschild reflecting objective that achieves diffraction-limited performance at f/2. This is an obscured design and we take advantage of the obscuration to place the CCD lens in the unused part. The CCD lens is easy to fabricate and align, and the entire system, including fold mirror, sits in a tube that can be cemented to the inside of the reflective objective.

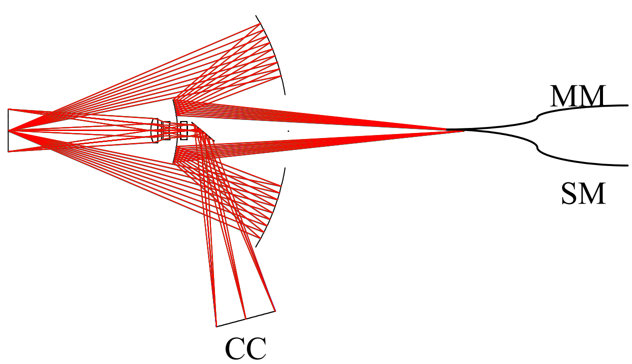

Figure 1: Raytrace of the optical head, combining confocal and wide-field optics. MM is the multimode fiber leading up to the reflectance spectrometer and SM the single mode fiber for the Raman portion. This design represents a significant evolution over our originally-proposed version.

It was not possible to implement this design in practice due to lack of funds. A set of commercial microscope objectives was used for experimentation.

2) Reflectance microspectrometer. As part of this task, we improved the confocal properties of the multimode fiber portion, demonstrating an improvement in vertical resolution by a factor of 2.3 over the earlier version. The vertical and horizontal resolutions are shown in Fig. 2.

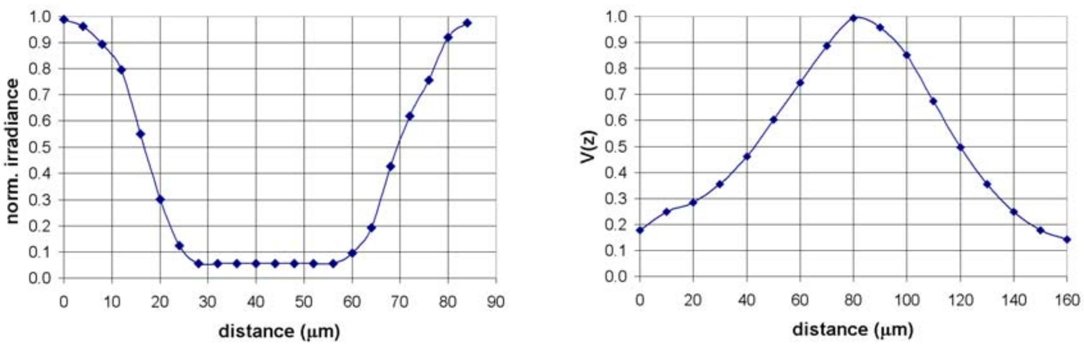

Figure 2. Left: Image of a 50 μm-wide slit through the multimode confocal fiber microscope. The residual signal at the bottom is due to the reflectivity of the glass substrate. 4x (de)magnification. A ~16 μm edge spread is observed at the 10-90% points. Right: Light intensity through a receiving fiber of 50-μm diameter as a function of focus. 4x (de)magnification, 0.35 objective NA. The vertical FWHM resolution shown is ~75 μm.

Lack of funds prohibited the construction of a stable spectrometer module with dedicated detector array. However, we were able to resolve the main question of the research regarding the stability of the signal through the fiber. We used a microbending cladding mode stripper to significantly alter the mode distribution in the fiber, and saw no change in the recorded spectrum. The spectra provided tantalizing hints for further research regarding the sample/optics interaction and the effect of the confocal mode operation on the depth of the observed absorption lines. This portion of the instrument was submitted as a MIDP proposal and received excellent reviews for potential science return and relevance, but was not funded.

3) Demonstration of the utility of fiber Bragg gratings in single-mode Raman spectroscopy. In this part, we examined the means through which two separate fiber Bragg gratings (FBGs) can be made to stabilize the laser diode wavelength and then extinguish the light from the diode. This work highlighted the difficulty of obtaining high-quality FBGs for anything other than telecommunications applications. The low-reflectivity gratings that were to be used for laser stabilization were not of sufficient quality (R too low). We were thus able to experiment only with the high-R grating. This was found to have an extinction of 8×10^{-4}, which was not up to the specification (10^{-6}). However, it is certain that better gratings can be made; the problem is identifying a manufacturer willing to undertake fabrication. In any case, in order to test the effects of temperature, we subjected this grating to changes in temperature and stress. Both effects produce a shift in the center wavelength. Thus an athermal design where stress compensates for temperature is possible to implement. Figure 3 shows the shift in the spectrum of the FBG as a function of temperature and stress. The data were obtained using the Raman spectrometer module that is discussed in the next section.

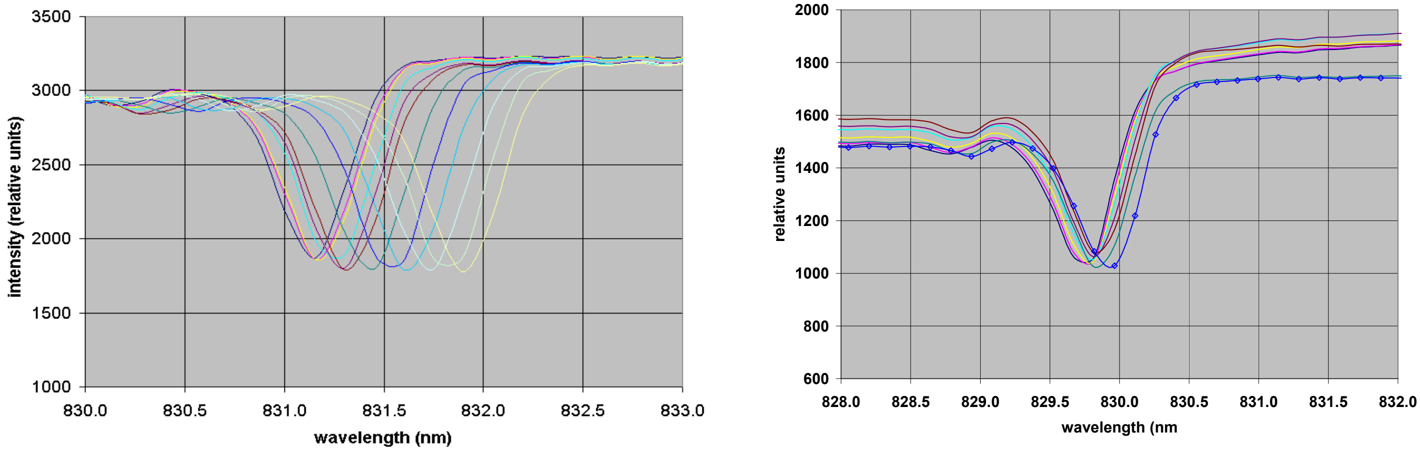

Figure 3. Left: Variation of the FBG spectrum with stress. The background illumination is provided by a superluminescent diode, the spectrum of which is filtered by the FBG. The dip shifts by ~1.7 nm for a total applied strain of $2x10^{-3}$. Right: Variation of the FBG spectrum with temperature. The leftmost curve is obtained for a temperature of 7^oC and the rightmost one for 40^oC. The observed temperature shift is 0.015 nm/deg. The absolute wavelength scale is only approximate and is not to be compared between the two pictures.

The confocal property of the single mode fiber probe was also investigated. Figure 4 shows the vertical resolution obtained. The horizontal resolution (edge spread) was 4 μm.

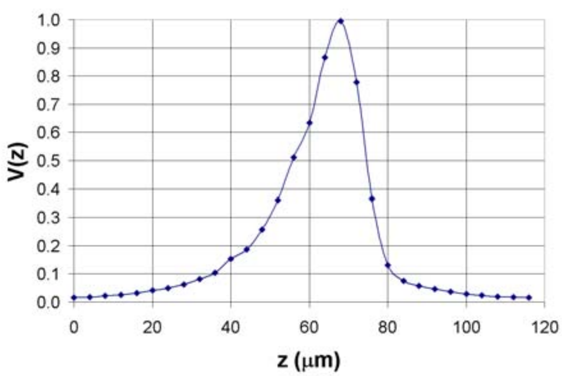

Figure 4. Light collected from a single mode fiber in a confocal arrangement, at 830 nm. A FWHM resolution of about 20 μm is demonstrated for 0.2 NA. The asymmetry in the curve is likely due to spherical aberration in the commercial objectives, which were not corrected for the infinite conjugate arrangement used.

4) Raman spectrometer module. A miniature spectrometer module was demonstrated. A new, fine-pitch (1.4 μm) grating was fabricated at MDL using E-beam lithography. This grating demonstrated outstanding phase continuity between panels (fields). It also was considerably steeper than previous gratings (27 deg. blaze angle compared with typically only a few degrees). The Raman spectrometer was assembled out of stock parts, with the grating being written on the convex face of a small planoconvex lens. A quick interferometric alignment method was developed that enabled alignment of the spectrometer module within ~1hr. The benchtop spectrometer module is shown in Fig. 5.

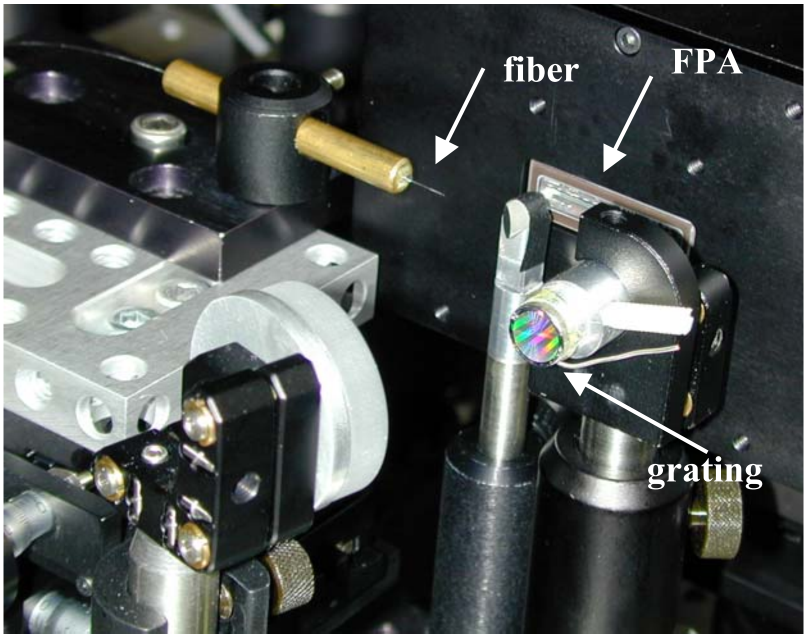

Figure 5. Assembled Raman spectrometer module, used to test resolution and to characterize the FBGs. Room lights diffracted from the grating are seen. For scale reference, the grating substrate is 10 mm in diameter (a dime is 18 mm).

C. SIGNIFICANCE OF RESULTS

These results open the way towards the development of an analytical spectroscopic capability on a rover with unprecedented potential science return, while at the same time reducing the volume and mass over competing approaches. The resulting instrument would be able to map the rover surroundings faster than a thermal IR spectrometer, be simpler to operate, and be more sensitive to water-bearing minerals. The microscopic portion would be able to examine individual mineral grains, map in three dimensions the surface of a rock or prepared sample, provide context information, return orders of magnitude more data than a Raman spectrometer alone, but use the Raman spectrometer whenever the discrimination capability of the reflectance portion fails, and identify iron-bearing minerals like a Mossbauer spectrometer but with high spatial resolution. The combination of all those capabilities in a compact instrument opens the way for smart-rover, autonomous Mars exploration.

D. FINANCIAL STATUS

The total funding for this task was $100,000, all of which has been expended.

E. PERSONNEL

In addition to the investigators, Leonard Wayne of Section 384 provided much-appreciated support with experimental setups and computer hardware and software.

F. PUBLICATIONS

1) P. Mouroulis, “Optical Design of a Reflectance/Raman Confocal Microspectrometer,” SPIE Proc. 4767, in press (2002).
2) P. Mouroulis, “Multimodal Imaging and Spectroscopy Platform”, *NASA Tech. Brief.,* NPO-30650